The Effect of Fuels and Test Cycles on Light-Duty Vehicle Exhaust Emissions

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Outline

- General Description
- Fuels
- Vehicles
- Test Procedures
- Data Analysis
- Results
- Conclusions
- Future Research

Program Participants

- **Funding**

  U.S. Department of Energy
  Energy Efficiency and Renewable Energy
  Office of Transportation Technologies
  Washington, D.C.

- **Program management**

  National Renewable Energy Laboratory
  Center for Transportation Technologies and Systems
  Golden, Colorado

- **Emissions testing laboratory**

  Automotive Testing Laboratories, Inc.
  East Liberty, Ohio

- **Test vehicles**

  Various agencies operating vehicles in the U.S. federal fleet

Test Program Rationale

U.S. Department of Energy

- Alternative fuels programs
  - Energy security
  - Renewable resources
  - Alternative fuel vehicle deployment
- 1988 Alternative Motor Fuels Act
- 1992 Energy Policy Act

U.S. Environmental Protection Agency

- Clean air programs
  - Control of emissions from mobile sources
  - Tightening emissions standards
  - New emissions testing procedures
  - Clean fuel and clean fuel fleet mandates
  - Reformulated gasoline programs
  - Emissions inventories
  - Air toxins
  - Ozone
  - Global warming
- 1970 Clean Air Act
- 1990 Clean Air Act Amendments

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Objective

To evaluate exhaust emissions from current production technology, light-duty alternative fuel vehicles over several emissions testing procedures

Test Procedures

- FTP-75
- Cold CO
- US06

Test Vehicles

- Alcohol flexible fuel
- Dedicated natural gas
- Bi-fuel natural gas
- Standard gasoline

Test Fuels

- Methanol
- Ethanol
- Natural gas
- Reformulated gasoline

Test Fuels

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Alcohol Fuels

Advantages

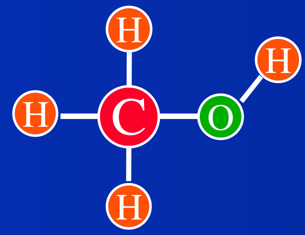
- Relatively simple chemical composition
- High octane rating
- High ratios of oxygen and hydrogen to carbon
- No sulfur
- Renewable resource

Disadvantages

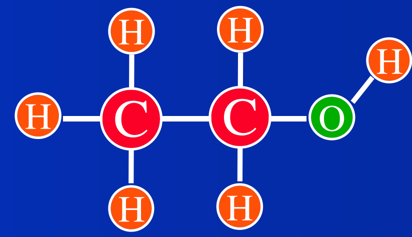
- Low energy content
- Corrosive/solvent nature
- Lower combustion temperature
- Aldehyde emissions
- Cost

Test fuel blends

- M85—85% methanol blended with 15% RFG
- E85—85% ethanol blended with 15% RFG



Methanol (CH_3OH)



Ethanol (C_2H_5OH)

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Natural Gas Fuels

Advantages

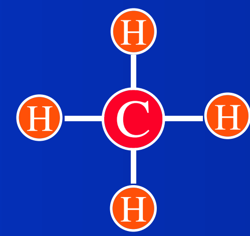
- Simple chemical composition
- High ratio of hydrogen to carbon
- High octane rating
- No sulfur
- Cost
- Domestic resource

Disadvantages

- Very low density
- Lack of lubricity
- Safety

Test fuel blends

- Methane 93.0%
- Ethane 3.5%
- Nitrogen 1.7%
- Carbon dioxide 0.8%
- Propane 0.7%



93% Methane (CH_4)

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Reformulated Gasoline

- Developed by industry
  (Auto/Oil Air Quality Improvement Program [AQIRP])
- California and federal mandates
- Reduced aromatics, olefins, and sulfur
- Increased oxygen

Advantages

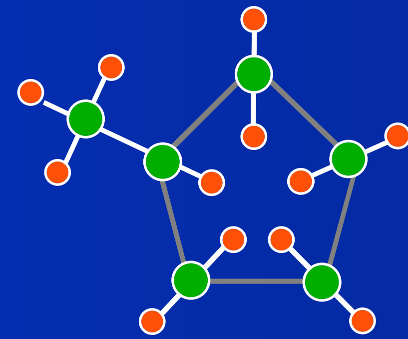
- Air quality improvements
- Existing infrastructure and production
- No vehicle modifications

Disadvantages

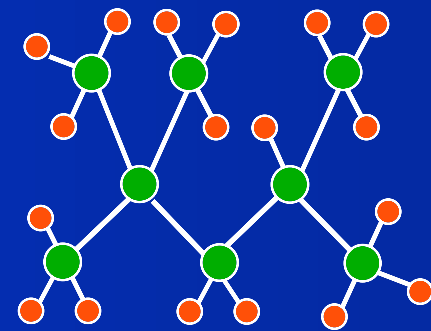
- Incremental improvements
- Non-domestic fuel
- Non-renewable

Test fuel

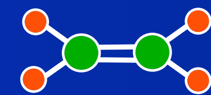
- California Phase II reformulated gasoline



Methyl-cyclo-pentane



Iso-octane



Ethylene

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Test Vehicles

CNG Vehicle Technology

- Dedicated natural gas
  - Single fuel system "optimized" for operation on natural gas
- Bi-fuel natural gas
  - Gaseous and liquid fuel systems on board
  - Capable of switching between fuels
  - "Compromised" fuel/emissions system controls

Typical features of natural gas vehicle

- High pressure fuel tanks—3600 psi
- High pressure fuel lines and gaseous refueling connector
- Fuel pressure regulator, temperature and pressure sensors
- Gaseous fuel injectors
- Special programming of electronic control module of air/fuel ratio calibration
- Hardened valve seats, stems and guides may be needed to reduce engine wear rates
- Dedicated vehicles do not need evaporative emissions control system
- Dedicated vehicles may include increased compression ratios

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1994 Dodge B250 Van

Dedicated CNG
5.2 liter V-8 engine

1996 Ford F150 Pickup

Bi-fuel CNG
4.9 liter V-6 engine
GFI control system

Alcohol Vehicle Technology

- Flexible-fuel vehicles
- Allow operation on a blend of liquid fuels from 85% alcohol with 15% gasoline to 100% gasoline in a single fuel system

Typical features of a flexible-fuel vehicle

- Alcohol-compatible fuel system components—stainless steel fuel tanks and lines, special alcohol compatible polymers in seals, gaskets, and hoses
- Increased volume fuel tank
- Increased flow volume fuel injectors
- Alcohol fuel sensor
- Special programming of electronic control module for air/fuel ratio calibration
- Hardened valve seats and related components to reduce engine wear rates
- Increased capacity evaporative emissions cannisters

1995 Dodge Intrepid

M85 flexible-fuel
3.3 liter V-6 engine

1995 Ford Taurus

M85 flexible-fuel
3.0 liter V-6 engine
FFV certified to TLEV

Number and Types of Test Vehicles

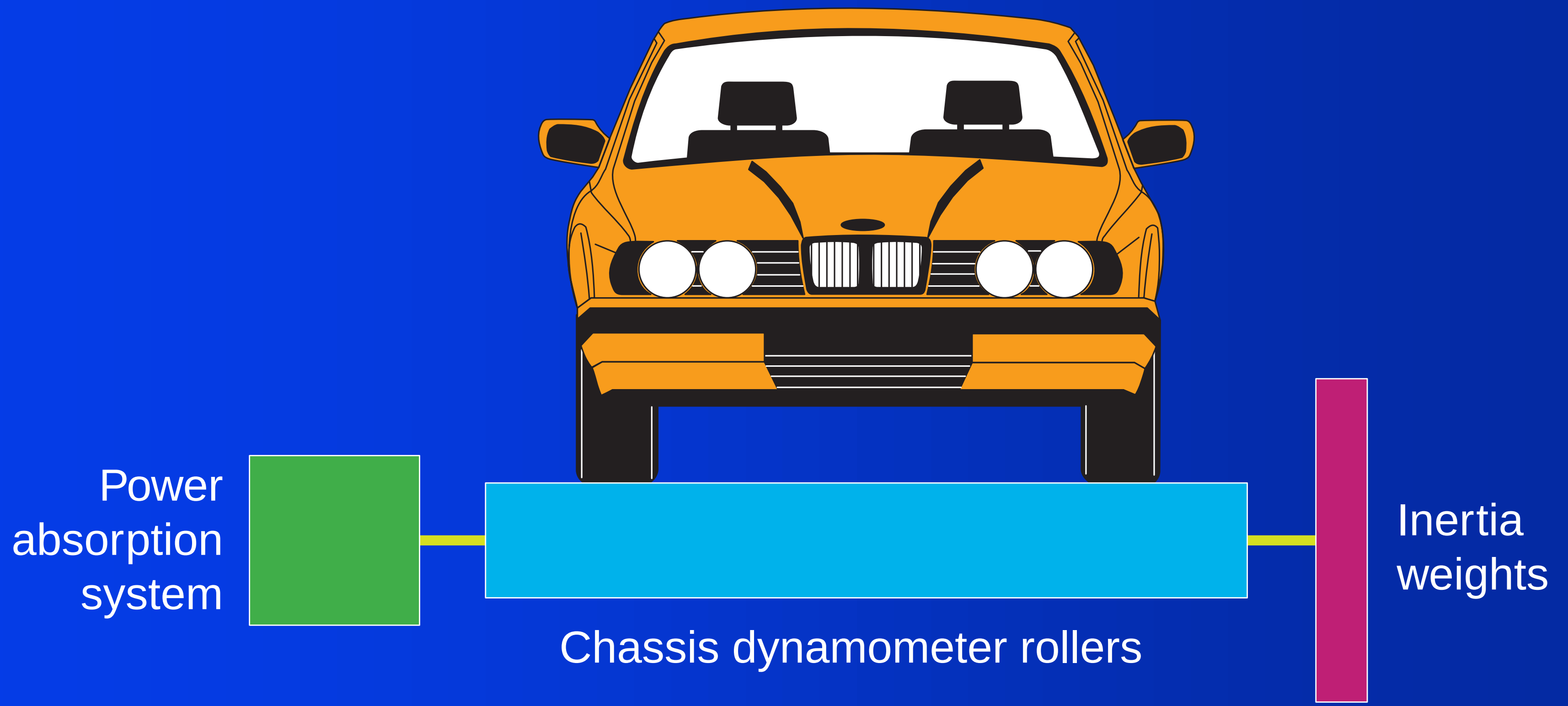
Vehicle Make	Vehicle Model	Model Year	Vehicle Type	Number of Test Vehicles	Test Fuel	Number of Repeat Tests	Total Number of Tests
Dodge	Intrepid	1995	FFV	4	M85	1	5
					RFG	1	5
			Standard	4	RFG	1	5
Ford	Taurus	1995	FFV	4	M85	1	5
					E85	1	5
					RFG	1	5
			Standard	4	RFG	1	5
Dodge	B250 Van	1994	Dedicated	4	CNG	1	5
			Standard	4	RFG	1	5
Ford	F150 Pickup	1996	QVM	4	CNG	1	5
					RFG	1	5
Test and vehicle totals				**28**		**11**	**55**

Test Procedures

Emissions Testing

- Federal test procedures—Code of Federal Regulations CFR 40, Part 86
- Chassis dynamometer exhaust emissions
- Federal regulated emissions
  - Hydrocarbons
  - Carbon monoxide
  - Oxides of nitrogen
- Aldehydes and alcohols
- Greenhouse gases
- Fuel economy

Schematic of Chassis Dynamometer



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1996 Ford Taurus on Chassis Dynamometer

Ford F150 Pickup on Chassis Dynamometer (Rear Wheel Drive)

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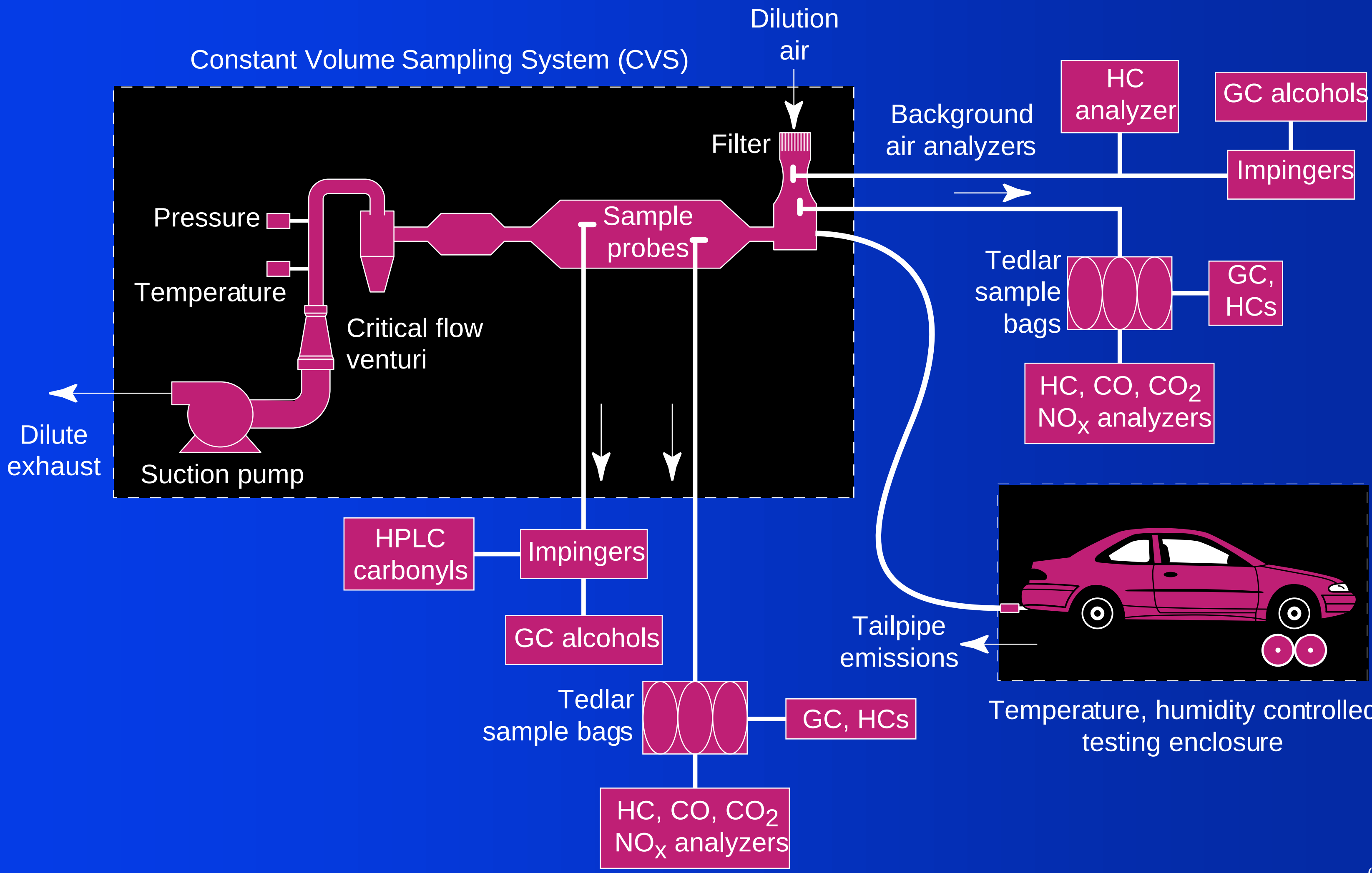
Exhaust Emissions Sampling System



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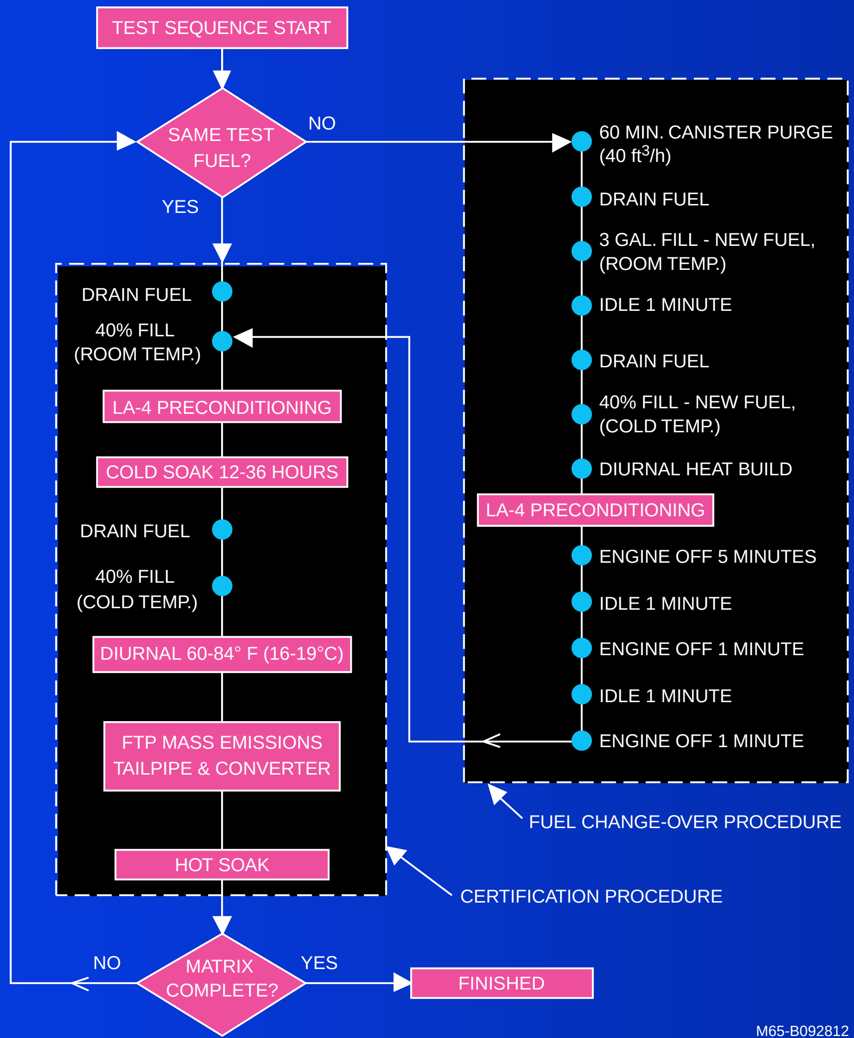
Exhaust Emissions Transfer Hose

Exhaust and Dilution Air Sampling Bags

FTP-75

- Cornerstone of federal test procedure for emissions certification and city fuel economy estimate
- Chassis dynamometer test cycle
- Three phases
  - Cold transient
  - Stabilized
  - Hot transient
- Fuel changeover procedure
- Evaporative emissions

FTP-75 Test and Fuel Changeover Procedure



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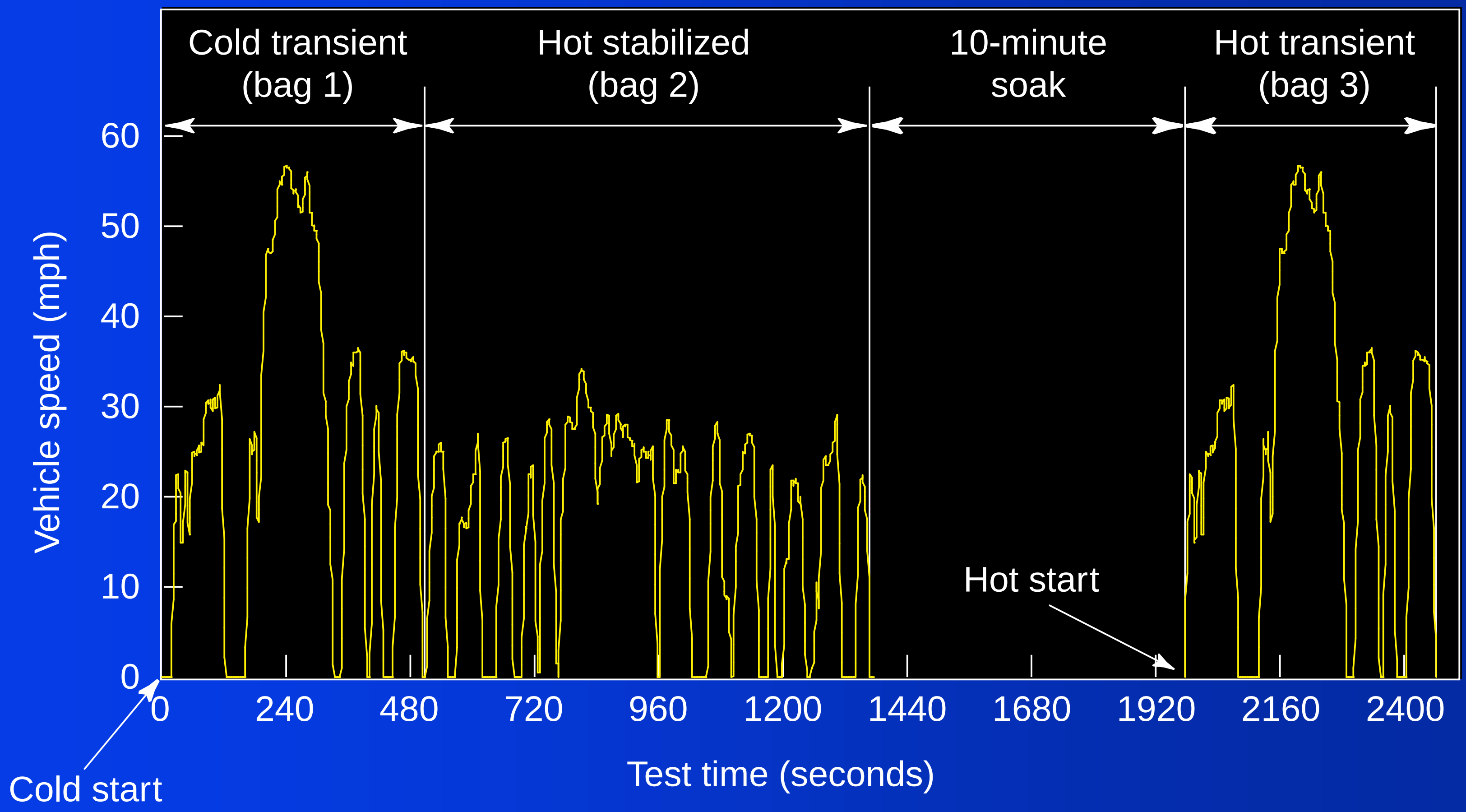
EPA FTP-75 Driving Cycle



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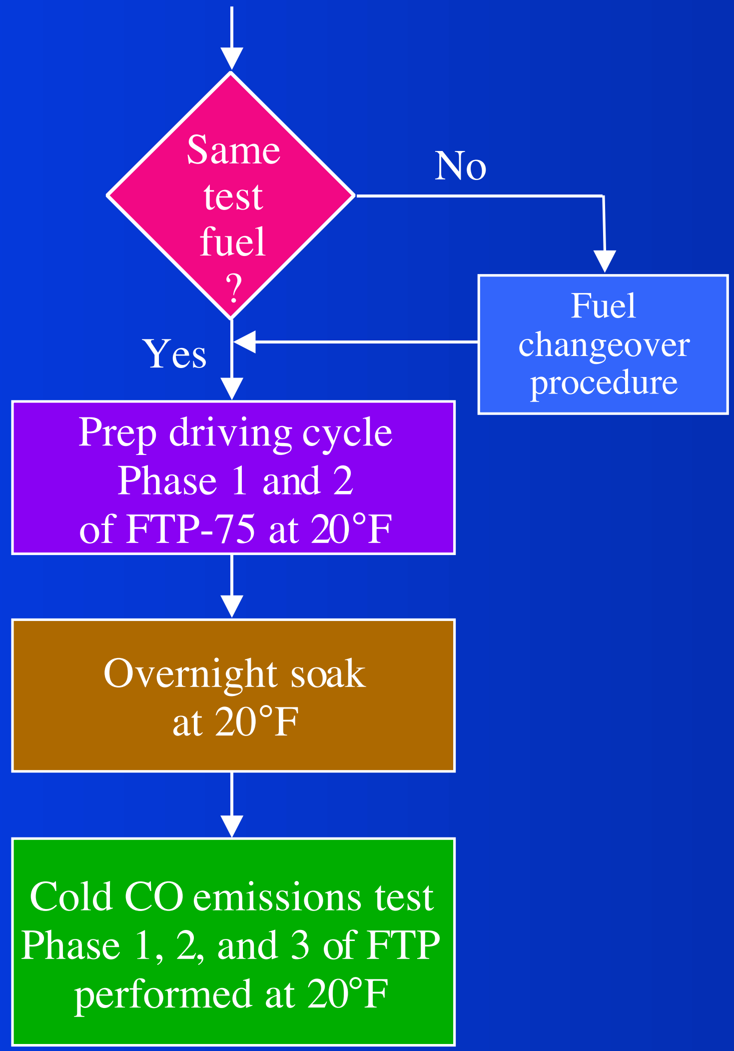
Cold CO Test Procedure



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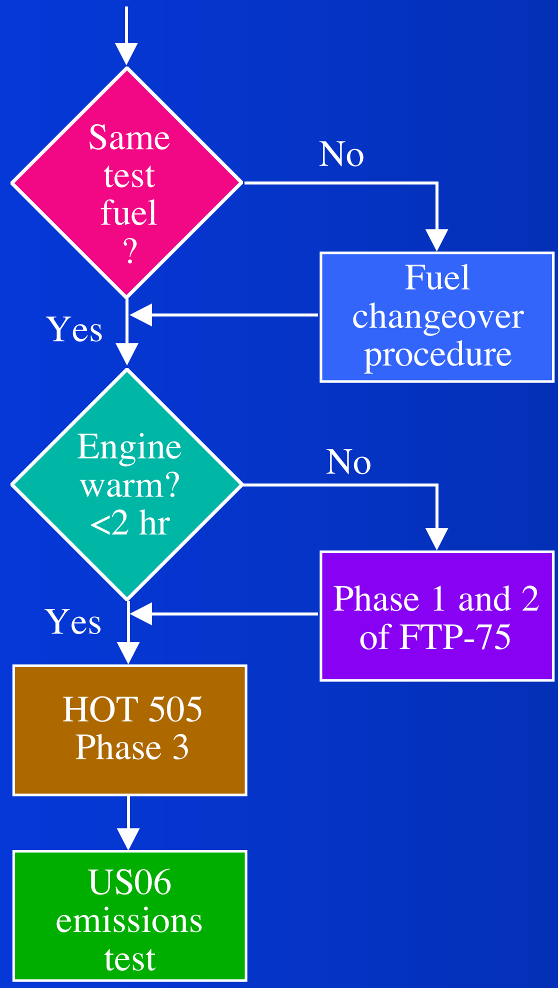
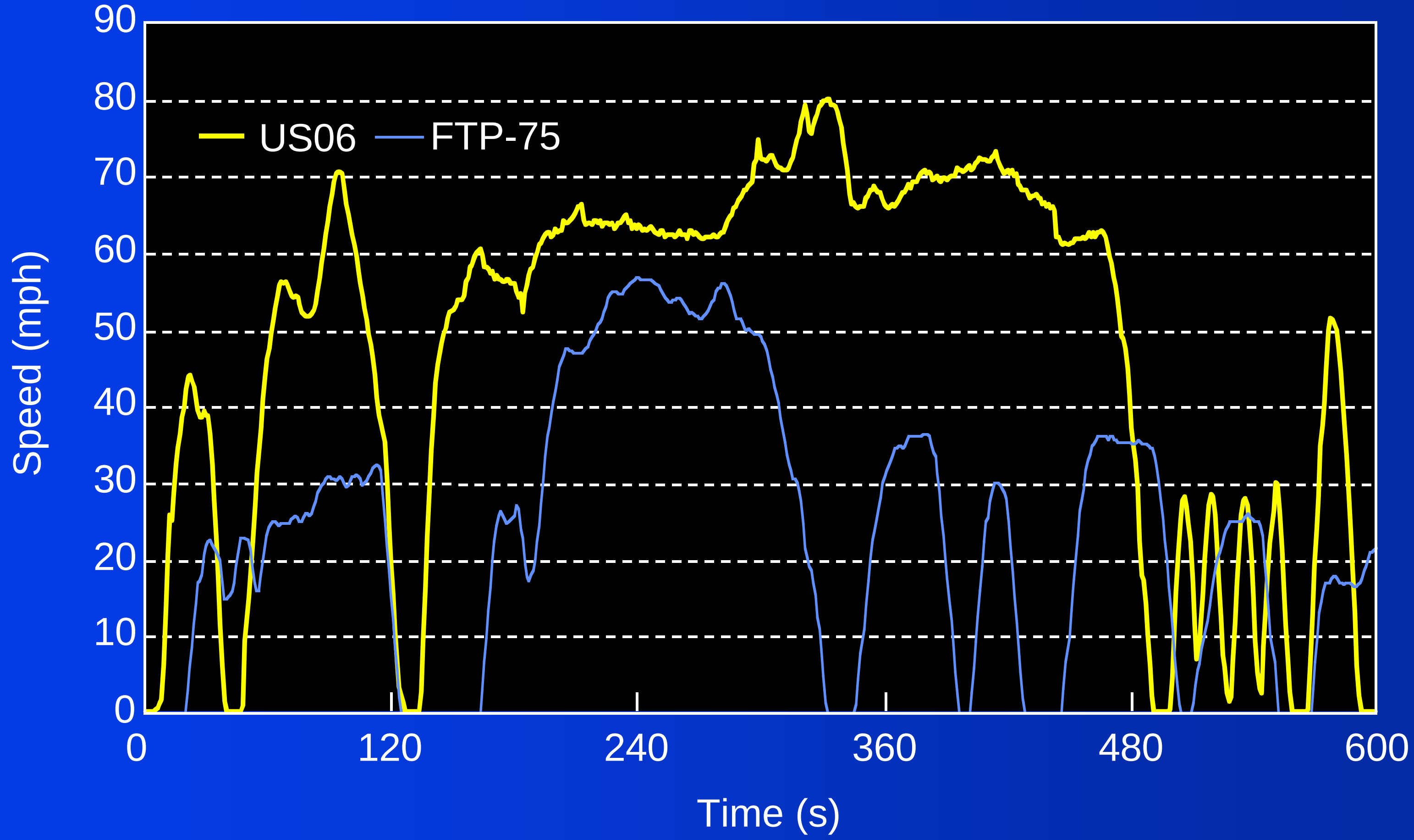
US06 Test Procedure



US06 and 600 Seconds of FTP-75



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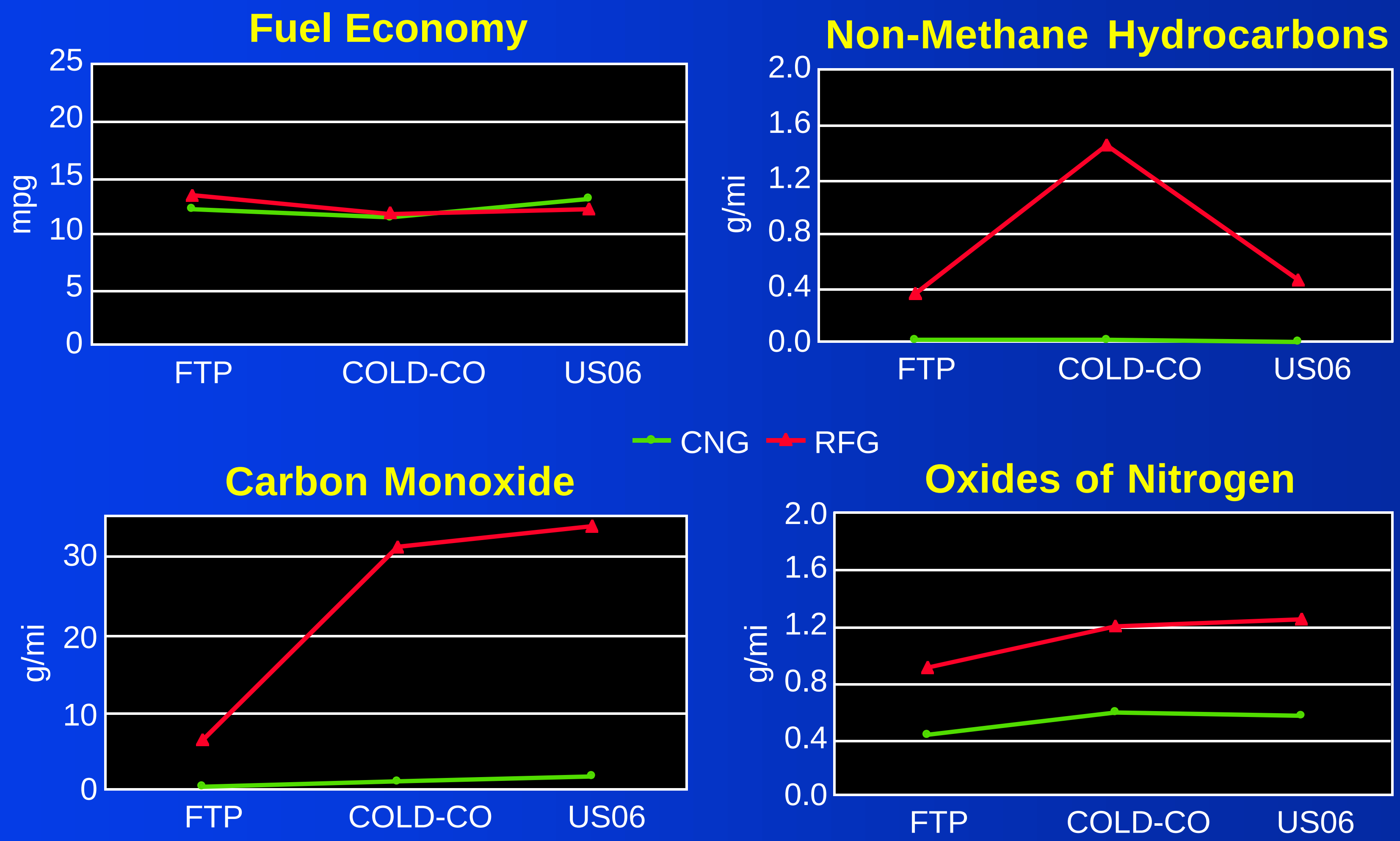
ANOVA

- Multi-variable analysis of variance
- JMP software
- Primary effects
  - Vehicles
  - Fuels
  - Test cycles
- Interactions
  - Fuels x Test cycles
  - Vehicle x Fuel
  - Vehicle x Test cycle
- F-test comparing variance between effects to an overall estimate of sample variance

Summary of Results

Dodge B250 Van



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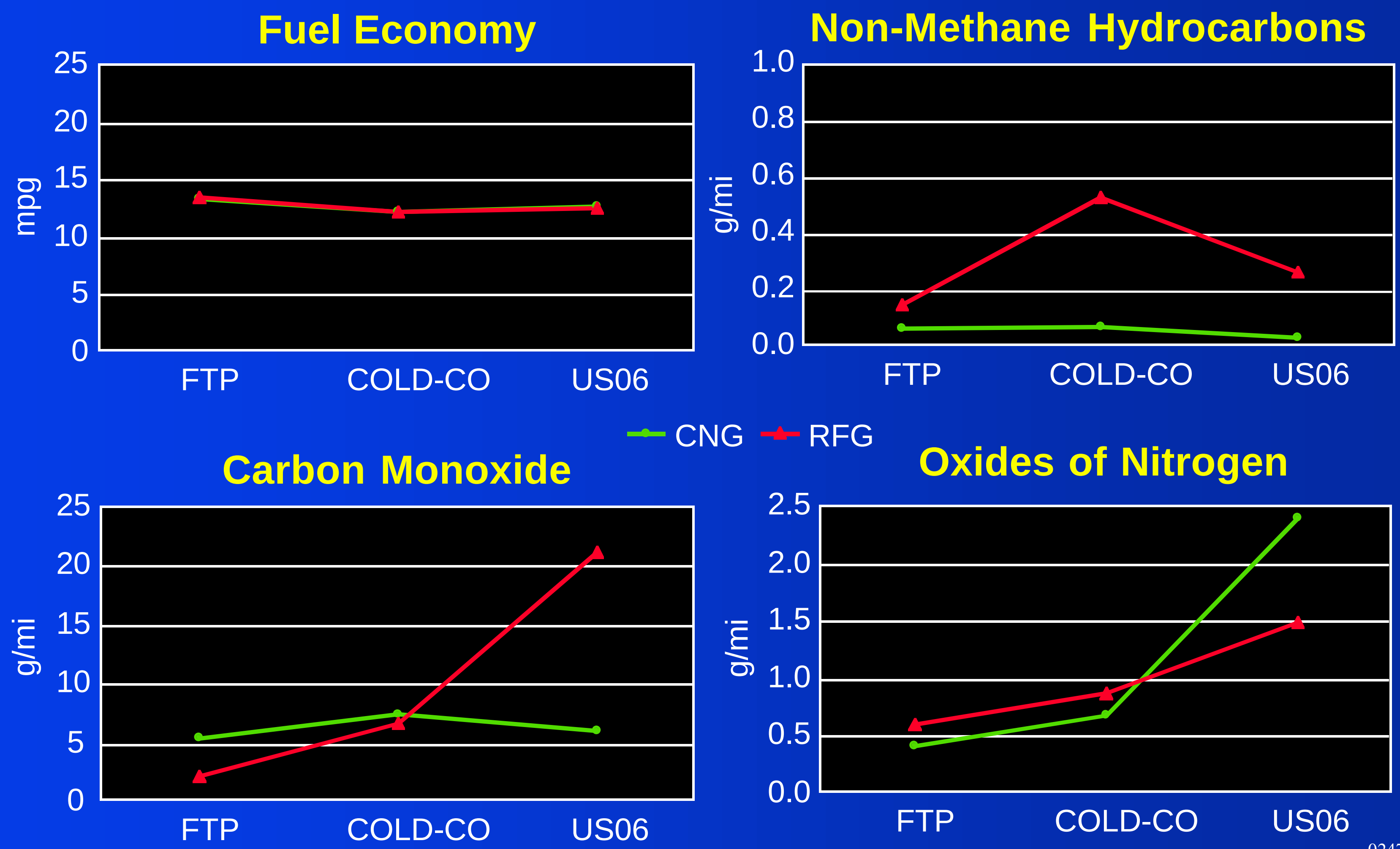
Ford F150 Pickup



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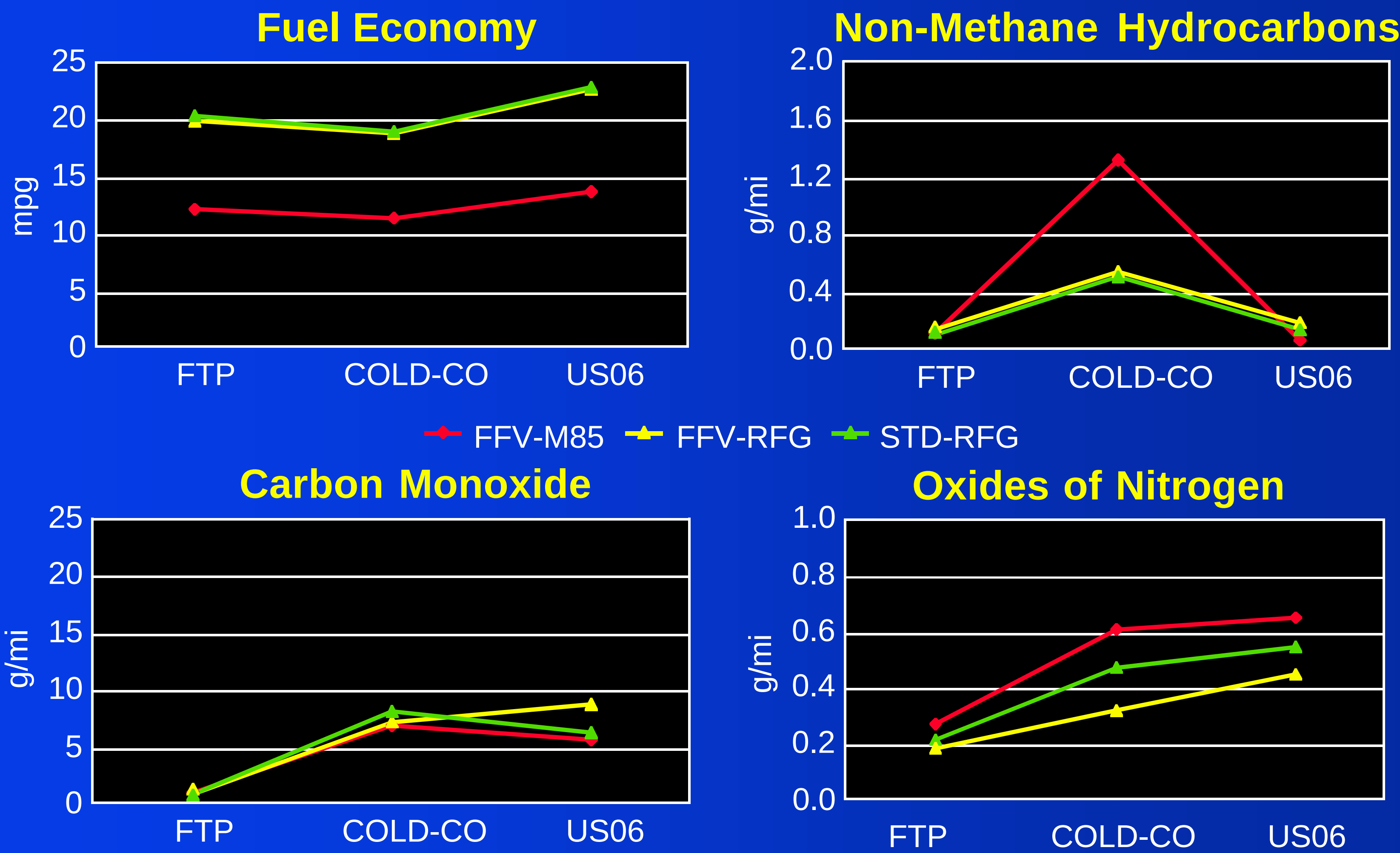
Dodge Intrepid



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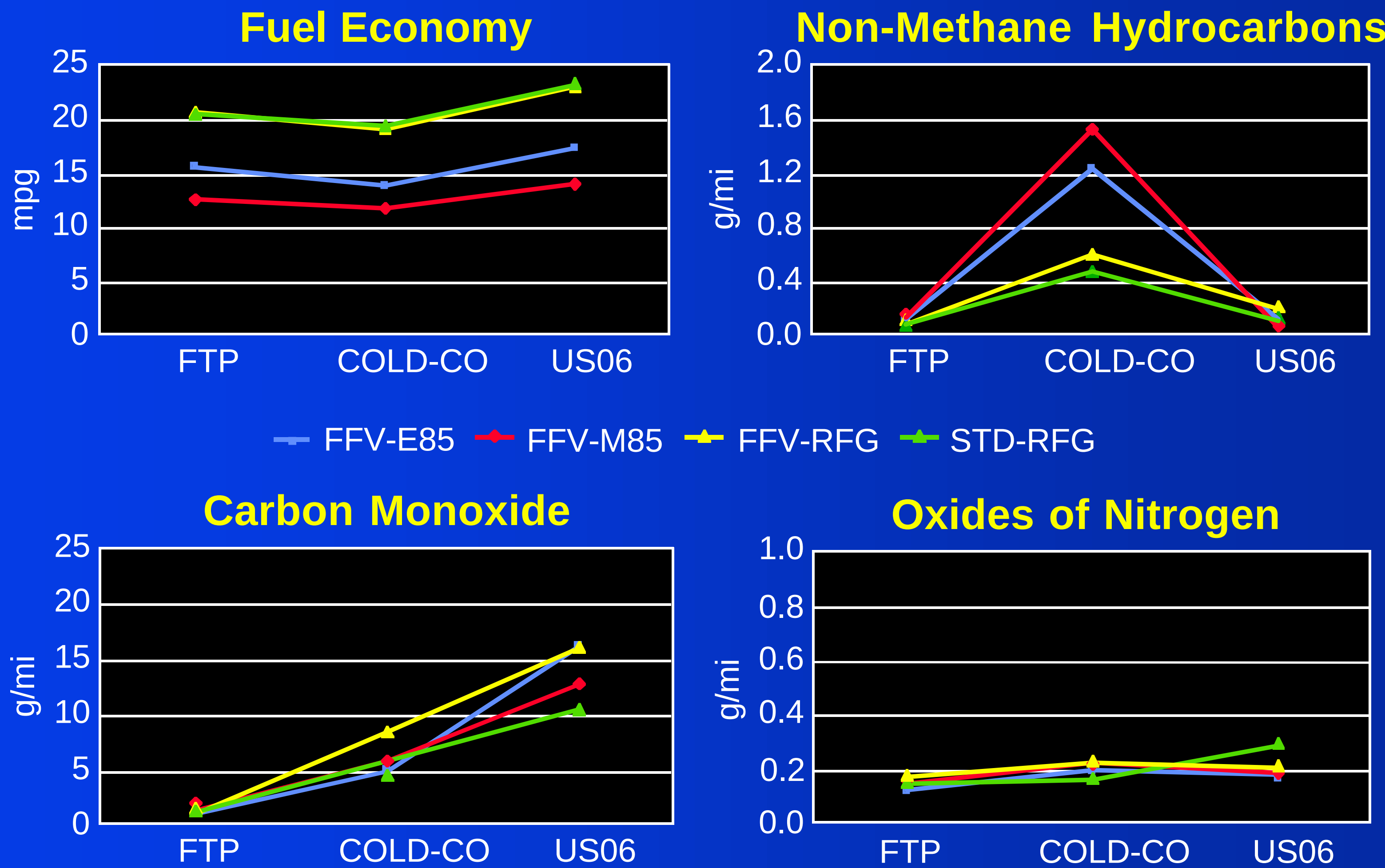
Ford Taurus



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Summary of Fuel Economy and Emissions Results

Cold CO Summary

		MPG	NMHC	THC	CO	NO_x	HCHO	CH_3CHO	CARBONYL	CO_2	CH_4
Alcohol											
FFV Intrepid	M85	blue ●	red ■	red ■	red ■	red ■	red ■	red ■	red ■	red ●	red ■
FFV Taurus	M85	blue ●	red ■	red ■	red ■	red ▲	red ■	red ■	red ■	red ●	red ■
FFV Taurus	E85	blue ●	red ■	red ■	red ■	red ▲	red ■	red ■	red ■	red ●	red ■
CNG											
CNG B250	CNG	blue ●	red ●	red ●	red ■	red ●	red ●	blue ●	red ●	red ●	red ●
QVM F150	CNG	blue ●	red ●	red ●	red ●	red ▲	red ●	blue ●	red ●	red ●	red ●
RFG											
FFV Intrepid	RFG	blue ●	red ■	red ■	red ■	red ■	red ▲	red ▲	red ▲	red ●	red ■
FFV Taurus	RFG	blue ●	red ■	red ■	red ■	red ●	red ▲	red ■	red ■	red ●	red ■
QVM F150	RFG	blue ●	red ▲	red ▲	red ■	red ■	blue ▲	blue ●	blue ●	red ●	red ●
Std Intrepid	RFG	blue ●	red ■	red ■	red ■	red ▲	red ▲	red ▲	red ▲	red ●	red ■
Std Taurus	COLD CO	blue ●	red ■	red ■	red ■	red ●	red ●	red ■	red ▲	red ●	red ■
Std B250	RFG	blue ●	red ■	red ■	red ■	red ●	red ▲	red ■	red ▲	red ●	red ■

red ● 0–50% increase — blue ● 0–50% decrease

red ▲ 50–100% increase — blue ▲ 50–100% decrease

red ■ >100% increase — blue ■ >100% decrease

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Summary of Fuel Economy and Emissions Results

US06 Summary

		MPG	NMHC	THC	CO	NO_x	HCHO	CH_3CHO	CARBONYL	CO_2	CH_4
Alcohol											
FFV Intrepid	M85	0–50% increase	0–50% decrease	0–50% decrease	>100% increase	>100% increase	50–100% decrease	0–50% increase	50–100% decrease	0–50% decrease	0–50% decrease
FFV Taurus	M85	0–50% increase	0–50% decrease	0–50% decrease	>100% increase	0–50% increase	50–100% decrease	50–100% decrease	50–100% decrease	0–50% decrease	>100% increase
FFV Taurus	E85	0–50% increase	0–50% increase	0–50% increase	>100% increase	0–50% increase	50–100% decrease	0–50% decrease	0–50% decrease	0–50% decrease	>100% increase
CNG											
CNG B250	CNG	0–50% increase	0–50% decrease	0–50% decrease	>100% increase	0–50% increase	50–100% decrease	0–50% increase	50–100% decrease	0–50% decrease	0–50% decrease
QVM F150	CNG	0–50% decrease	50–100% decrease	0–50% decrease	0–50% increase	>100% increase	50–100% decrease	0–50% decrease	50–100% decrease	0–50% increase	0–50% decrease
RFG											
FFV Intrepid	RFG	0–50% increase	0–50% increase	0–50% increase	>100% increase	>100% increase	0–50% decrease	0–50% decrease	0–50% decrease	0–50% decrease	50–100% increase
FFV Taurus	RFG	0–50% increase	>100% increase	>100% increase	>100% increase	50–100% increase	50–100% decrease	0–50% decrease	0–50% decrease	0–50% decrease	>100% increase
QVM F150	RFG	0–50% decrease	50–100% increase	50–100% increase	>100% increase	>100% increase	50–100% decrease	0–50% decrease	0–50% decrease	0–50% increase	0–50% increase
Std Intrepid	RFG	0–50% increase	0–50% increase	0–50% increase	>100% increase	>100% increase	50–100% decrease	0–50% decrease	0–50% increase	0–50% decrease	0–50% increase
Std Taurus	RFG	0–50% increase	0–50% increase	0–50% increase	>100% increase	0–50% decrease	50–100% decrease	0–50% decrease	0–50% decrease	0–50% decrease	>100% increase
Std B250	RFG	0–50% decrease	0–50% increase	0–50% increase	>100% increase	0–50% increase	50–100% decrease	0–50% decrease	0–50% decrease	0–50% increase	0–50% increase

● 0–50% increase ● 0–50% decrease

▲ 50–100% increase ▲ 50–100% decrease

■ >100% increase ■ >100% decrease

Key Results

ANOVA showed that the test cycle, fuel and the interactions between test cycles and fuels had statistically significant impacts on vehicle emissions at the 95% confidence level

- Cold CO versus FTP
  - Increase in nearly all exhaust emissions constituents
  - Decrease in fuel economy for all vehicles and fuels
- US06 versus FTP
  - Increase in CO and NO_x
  - Increased fuel economy except for gasoline van and bi-fuel pickup
  - Decrease in aldehyde emissions
- Alcohol flexible fuel vehicles
  - Significantly larger increase in hydrocarbon and aldehyde emissions on the Cold CO test compared to other fuels
  - Small increases in fuel efficiency compared to RFG across all cycles
- Dedicated CNG van
  - Relatively unreactive to changes in driving cycles
  - Maintained large emissions benefits compared to RFG across all cycles
- Bi-fuel CNG pickup
  - NMHC and CO were relatively unreactive to changes in driving cycle
  - Large increase in NO_x emissions for US06 test
  - Emissions compared to RFG was mixed

Conclusions

- Driving behaviors and conditions play an important role in vehicle emissions.
- The various alternative fuels and vehicle designs can have different emissions reactions to the driving conditions.
- Additional development is needed to control hydrocarbon emissions from alcohol fuel vehicles under cold start conditions.
- Dedicated CNG vehicles exhibit a strong potential for reducing emissions under the three test procedures used in this study.
- Bi-fuel CNG vehicles may not be as effective as dedicated CNG vehicles in reducing exhaust emissions.

Additional Research

- Latest alternative fuel vehicles
  - Improvements to ethanol flexible fuel vehicle
  - Latest dedicated CNG vehicles advertising even lower emissions
  - Improvements to bi-fuel CNG vehicle fuel system control
  - New bi-fuel LPG vehicles
- Second by second emissions and air/fuel ratio data
- Detailed hydrocarbon speciation
- Particulate Matter (PM) measurements